Microhabitat selection varies by sex and age class in the endangered green and golden bell frog *Litoria aurea*

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ABSTRACT

Although amphibians are one of the most threatened animal groups, little published evidence exists on effective management programs. In order for conservation initiatives to be successful, an understanding of habitat use patterns is required to identify important environmental features. However, habitat use may differ between the different sexes and age classes due to different behavioural and resource requirements. For this study, we compared microhabitat use during the active breeding season among the sexes and age classes in the endangered green and golden bell frog *Litoria aurea*, a species which has had several failed management programs. We found aquatic vegetation was selected for by every *L. aurea* class, and should be the focus of future management plans for this species. Females were the only class to select for terrestrial vegetation more than availability. Increasing the amount of terrestrial vegetation around ponds may help encourage female occupancy, and possibly improve management outcomes, as they are typically a limiting resource. Although large rock piles have been used in past *L. aurea* habitat management, they were selected for by adults and juveniles, but not metamorphs. Therefore, large rocks may not be necessary for captive breeding portions of management initiatives, which typically only involve tadpoles and metamorphs prior to release. The results indicate that the most appropriate management plans should contain a habitat mosaic of various microhabitats, such as a large proportion of aquatic and terrestrial vegetation with patches of bare ground and a small proportion of rocks for basking and shelter. Recognizing differences in microhabitat use patterns between individuals in a population and implementing them into management strategies should be a pivotal step in any conservation plan.

Introduction

The current global biodiversity crisis has heightened the need for effective management of threatened species. For conservation initiatives to be successful, an understanding of habitat use patterns is required to determine how species are affected by natural and human-driven environmental changes (Mao *et al.* 2005; Sawyer *et al.* 2006; Wilson *et al.* 2016). These insights may help to build a basis for optimal decision-making and management strategies (Chetkiewicz *et al.* 2006; Kowal *et al.* 2014; Steen *et al.* 2014). A common method used by ecologists when making habitat assessments is to identify important habitat features for the species through a comparison of habitat use with its availability (Johnson 1980). However, it is unlikely that a particular habitat type will be uniformly used by a given species across its range. The favourability of habitat features are likely to vary depending on factors such as predation risk (Heithaus and Dill 2002; Mao *et al.* 2005), conspecific attraction (Pizzatto *et al.* 2015), preference toward natal habitat features (Stamps and Swaisgood 2007), disease (Threlfall *et al.* 2008), season

(Pratt and Smokorowski 2003; Zengeya *et al.* 2014), loss of natural habitat (Brand and Snodgrass 2010), food availability (Heithaus and Dill 2002), population density (Erős *et al.* 2005), and anthropogenic activities (Grindal and Brigham 1999; Mattson *et al.* 1987). By identifying variabilities in habitat use we can increase our understanding of the functional aspects of species habitat ecology and implement these features in future conservation management strategies.

Within a population, habitat preferences may also differ due to individual behavioural and resource requirements. Habitat use studies typically examine the species as a whole, without subdivision into life stages or sex classes (Barton *et al.* 1992; Furlonger *et al.* 1987; Medellin and Equihua 1998; Peña *et al.* 2015; Tew *et al.* 2000; Williams-Guillén *et al.* 2006). Although populations typically face a trade-off between survival and condition to maximize fitness, different requirements between males and females can result in differences in how the sexes

interact in their environment. Differences in habitat use between the sexes have been found in animals such as western barbastelle bats, *Barbastella barbastellus* (Hillen *et al.* 2011); American kestrel, *Falco sparveriushas* (Ardia and Bildstein 1997); ruffed grouse, *Bonasa umbellus* (Whitaker *et al.* 2006); tawny owls, *Strix aluco* (Sunde and M. Redpath 2006), red kangaroos, *Macropus rufus* (Johnson and Bayliss 1981); aphid parasites, *Diaeretiella rapae* (Read *et al.* 1970); and western toads, *Bufo boreas* (Bartelt *et al.* 2004; Bull 2006). Some of these differences in habitat use have been attributed to the different response by the sexes to density affects, such as in the yellowfin sole, *Limanda aspera* (Bartolino *et al.* 2010); breeding season differences, as found in the Alaskan moose, *Alces alces gigas* (Oehlers *et al.* 2011); and to human hunting, such as in wild boars, *Sus scrofa* (Saïd *et al.* 2012). Habitat requirements are also likely to differ substantially between earlier and later stages of life. Differences among life stages in habitat use have been reported in marsupials (Johnson and Bayliss 1981), birds (Whitaker *et al.* 2006), fish (Sempeski and Gaudin 1995), turtles (Arthur *et al.* 2008), and amphibians (González-Bernal *et al.* 2015; Searcy *et al.* 2013).

It is therefore essential to understand not just how a population uses available habitat, but also how habitat is used at the microhabitat scale by individuals to fully recognize any differences between the sex and life stages. This is exemplified by habitat use studies that focus on only one gender (Clark *et al.* 1993; Dunn and Braun 1986) or life stage (Harrel *et al.* 1996; Muhlfeld and Marotz 2005), which if the results are generalized to describe the species as a whole, may result in wrong assumptions about habitat requirements. Consequently, if differences in microhabitat preferences aren't considered, the success of interventions such as habitat creation, rehabilitation, and habitat management for threatened species may be severely limited.

Difficulties in establishing successful habitat interventions have been observed in many animal species, most notably in amphibians. Amphibians are one of the most globally threatened animal group (IUCN 2012; Vié *et al.* 2009), highly sensitive to environmental changes, and are essential components in many ecological communities (Blaustein and Wake 1995; Blaustein *et al.* 1994; Semlitsch 2002; Vos and Chardon 1998; Wyman 1990). Due to their high conservation priority, small size, high fecundity, and minimal resources required, they are considered a model candidate for conservation programs (McFadden *et al.* 2008). However, little published evidence exists for successful management, with only 13 of the 110 programs reported in the literature having resulted in a self-sustaining population (Griffiths and Pavajeau 2008). Although research has been conducted on the general habitat requirements of threatened amphibians (Baldwin *et al.* 2006; Graeter *et al.* 2008; Laurila 1998; Wassens *et al.* 2010; Williams *et al.* 2012) and their microhabitat preferences (Blomquist and Hunter 2010; Garnham *et al.* 2015; Hamer *et al.* 2003; Heard *et al.* 2008; Hossack *et al.* 2009; Seebacher and Alford 2002; Smits 1984), the failure rate of establishing self-sustaining populations remains high. These failures indicate that inadequate background research has been carried out on the threats, life history, behaviour, as well as the habitat requirements of these species. Successful conservation outcomes may be improved not only by removing and dealing with the original or persisting key threatening processes, but also through better understanding of their habitat requirements, especially in amphibians which have complex biphasic life cycles.
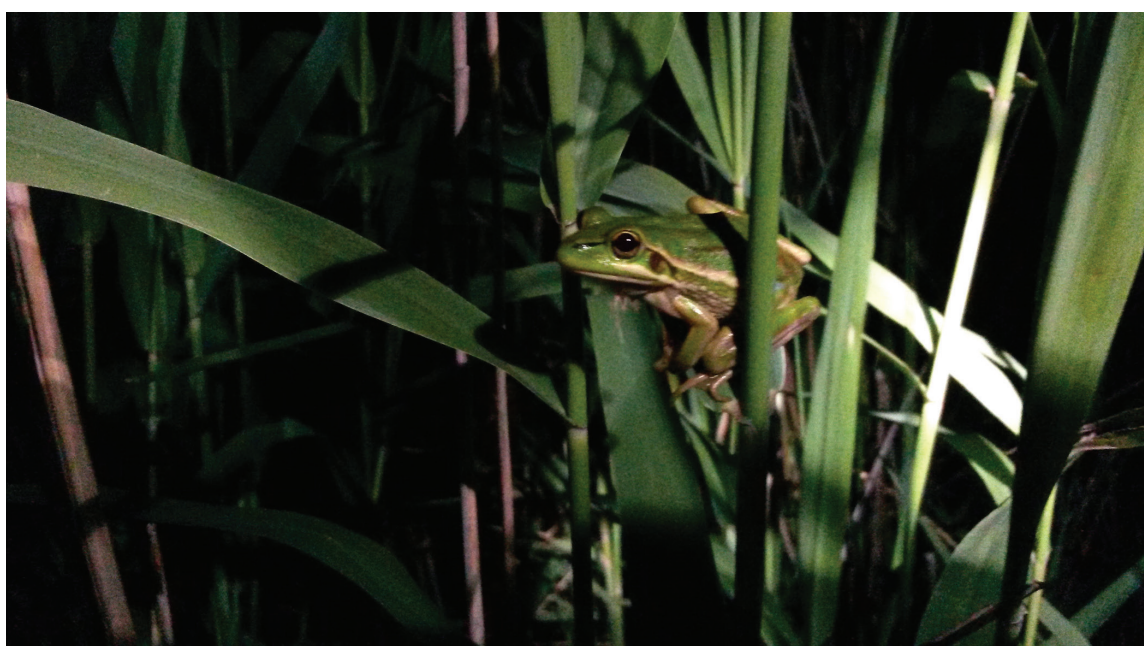

Figure 1. An adult green and golden bell frog, *Litoria aurea* on aquatic vegetation, *Typha orientalis*. Photo: Jose Valdez.

The green and golden bell frog *Litoria aurea* is one species faced with many of these conservation challenges (Fig. 1). This Australian species has undergone disease and habitat disturbance driven declines since the 1970s (Goldingay 2008; Mahony *et al.* 2013; White and Pyke 2008b). Due to its frequency of occurrence in areas of high development activity, it has had the most conservation management proposals of any Australian amphibian (Germano *et al.* 2015). As a colonizing and generalist species, *L. aurea* should be an ideal candidate for producing successful conservation programs. However, despite the use of habitat templates based on perceived microhabitat selection paradigms, nearly all habitat creation and reintroduction plans have been unsuccessful in producing a self-sustaining breeding population (Daly *et al.* 2008; Pyke *et al.* 2008; Stockwell *et al.* 2008; White and Pyke 2008a). To date, the most successful habitat creation program to result in a self-sustaining population has been at Sydney Olympic Park. This project required considerable financial input resulting in a 19-fold increase in available frog habitat (Darcovich and O'Meara 2008; O'Meara and Darcovich 2015; Pickett *et al.* 2013), and may have increased its success due to the presence of an established resident population that were able to colonise the newly-created habitat areas created nearby. Recognizing the microhabitat needs of the

sexes and life stages may help to understand the habitat components that confer survival in their remaining sites, help improve future captive breeding and habitat creation/restoration programs, as well as shed light on previous *L. aurea* habitat research.

In this study, we examined microhabitat use to availability in one of the last remaining extant population of *L. aurea* in the Hunter River Valley. The objective was to determine whether *L. aurea* actively select for and use microhabitat features similarly between the sexes and life stages. By comparing microhabitat selection between sex and age classes, we hoped to determine what microhabitat features are being used by the different classes to better inform future management programs.

Methods

Study site

The study was conducted across Kooragang Island which is located in the Hunter River estuary of New South Wales, Australia (-32°51'48.5634, 151°44'29.3634) (Fig. 2). This area represents one of the last remaining and largest extant *L. aurea* populations in the region (Hamer and Mahony 2010). The island is a heterogeneous estuarine landscape containing a

Figure 2. All the surveyed pond sites (in red and with identification numbers) across Kooragang Island, Newcastle, New South Wales. Image created with ArcMap 10.1.

range of habitats including wet pasture, salt marsh, remnant forest, mangrove, and freshwater wetlands (Day *et al.* 1999). It has a history of extensive land clearing and hydrological alterations for agricultural and industrial development (Hamer and Mahony 2010). The northern half of the island is reclaimed and part of the Hunter Wetlands National Park, while the southern half is highly industrialized with waste dump sites, industrial rail loops, and coal loading facilities for the Port of Newcastle (Hamer and Mahony 2010).

Field methods

Monthly surveys were conducted on Kooragang Island during the breeding season (September-April, inclusive) for a three-year period from April 2011 to April 2014, throughout 58 ponds (size range=31 m² to 250,332 m², average=8,094 m²) (Fig. 2). Standardized visual encounter surveys (VES) involved nocturnal searches for *L. aurea* within ponds, aquatic vegetation, and surrounding terrestrial microhabitat within 1 m of the edge of the waterbody (Fig. 3) (Bower *et al.* 2014; Crump and Scott 1994). All microhabitat features were inspected and any individuals that were encountered were captured by hand using a disposable plastic bag to prevent disease transmission. The location and microhabitat type of all

individuals detected were recorded. Surveys were timed with no overlap between searchers and determined to be finished when all areas were thoroughly searched.

All frogs captured were processed by measuring their snout to vent length (SVL) and body weight (Fig. 4). We determined the sex and age class of all individuals based on secondary sexual characteristics. Individuals with an SVL of less than 45 mm were recorded as metamorphs if they had a tail with developed front and hind limbs, or as juveniles if they had resorbed their tail. Frogs larger than 45 mm were recorded as males if nuptial pads were present and as females if nuptial pads were absent (Hamer 1998). After individuals were weighed and measured they were released back at the site of capture.

Habitat availability among surveyed ponds on Kooragang Island was measured annually using quadrat-based stratified sampling methods (Krebs 1999). The landscape was stratified within the waterbodies and the pond edge, with microhabitat recorded as a proportion of the total area. Habitat features were divided into groups (see Table 1. Functional groups and descriptions of the available microhabitat used in occupied ponds by

Figure 3. Examples of waterbodies nocturnally surveyed across Kooragang Island, including aquatic and terrestrial vegetation, rocks, and open water microhabitats. Photo: Jose Valdez.

Figure 4. A female green and golden bell frog, *Litoria aurea*, about to be weighed, measured and microchipped. Photo: Jose Valdez.

the green and golden bell frogs Litoria aurea between April 2011 and April 2014 on Kooragang Island.) for ease of analysis.

Data Analysis

Chi-square analysis was used to determine differences in microhabitat use between *L. aurea* classes (males, females, juveniles and metamorphs). Availability of microhabitats for each class was determined by the total percentage cover of microhabitats in the ponds where frogs of that class were found. The expected number of *L. aurea* for each class was found by multiplying the proportion of available microhabitats for the class by the

total number of individuals found in the class. To account for differences in detectability between microhabitats, an adjusted count was obtained by dividing the observed number of individuals found in each microhabitat by the probability of *L. aurea* detection for that microhabitat (Valdez *et al.* unpublished data). Chi-square values were then calculated by comparing the adjusted number of individuals found in each microhabitat with the expected number given the proportion of microhabitat availability. If a microhabitat was used more than expected it would be assumed to be preferred as a resource. This study design assumed that detectability within microhabitats did not differ between classes.

Results

A total of 964 observations were made during the surveys between 2011 and 2014. These included 294 males, 300 females, 329 juveniles, and 41 metamorphs among the different ponds on Kooragang Island (Figure 5).

The frequency of observed microhabitat use differed between classes from the frequency expected for bare ground ($\chi^2=336.8$, p<0.001), rocks ($\chi^2=209.17$, p<0.001), terrestrial vegetation ($\chi^2=36.9$, p<0.001), aquatic vegetation ($\chi^2=429.2$, p<0.001), and water ($\chi^2=415.7$, p<0.001). After incorporating probability of detection, microhabitats were not used in the same proportion as was expected for males ($\chi^2=257$, p<0.001), females ($\chi^2=1615.9$, p<0.001), juveniles ($\chi^2=377.1$, p<0.001), and metamorphs ($\chi^2=61.7$, p<0.001).

Bare ground was used more than expected by males ($\chi^2=103.7$, p<0.001), females ($\chi^2=1083.2$, p<0.001), and juveniles ($\chi^2=90.8$, p<0.001), but used as expected by metamorphs ($\chi^2=0.2$, p=0.65) (Figure 6a). Rocks were used more than expected by males ($\chi^2=46.2$, p<0.001), females ($\chi^2=284.4$, p<0.001), and juveniles ($\chi2=2.5$ p=0.11) but as expected for metamorphs ($\chi2=0.5$, p=0.49) (Figure 6b). Terrestrial vegetation was used more than expected by females ($\chi2=15.6$, p<0.001); less than

Table 1. Functional groups and descriptions of the available microhabitat used in occupied ponds by the green and golden bell frogs, *Litoria aurea* between April 2011 and April 2014 on Kooragang Island.

| Microhabitat	Description	Example
Aquatic vegetation	Aquatic vegetation inside or around the margin of ponds	*Baumea articulata, Schoenoplectus validus, Typha orientalis, Bolboschoenus* spp., *Juncus* spp., *Schoenus* sp., *Azolla* sp., and other submerged plants and algae species
Terrestrial vegetation	Vegetation occurring outside but not inside a pond	Shrubs (*Acacia* spp.), trees (*Casuarina* spp., *Eucalyptus* spp.), grass (*Kikuyu, Trifolium* spp.)
Rock	Hard substrate with a large grain size (>10 cm)	Large rocks, bricks, or other similar substrates
Bare ground	Substrate with small grain size (<10 cm) with little to no cover	Open dirt ground, mud, or leaf litter
Open water	Open water without aquatic vegetation	Open water
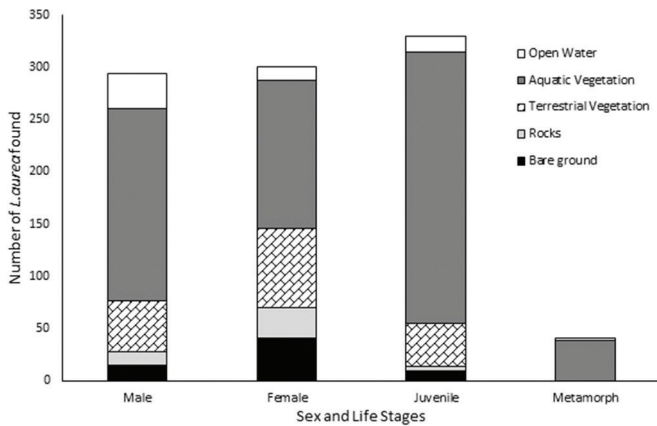
Figure 5. Total number of green and golden bell frogs *Litoria aurea* observed in different microhabitat types across Kooragang Island, New South Wales, Australia.

expected for males ($\chi 2 = 7.33$, p<0.001), and metamorphs ($\chi 2 = 5.4$, p=0.02); and as expected for juveniles ($\chi 2 = 1.59$, p=0.21), (Figure 6c). Aquatic vegetation was used more than expected by every class: males ($\chi^2 = 57.9$, p<0.001), females ($\chi^2 = 53.9$, p<0.001), juveniles ($\chi^2 = 159.4$, p<0.001), and metamorphs ($\chi^2 = 39.7$, p<0.001) (Figure 6d). Open water was used less than expected by all *L. aurea* classes; males ($\chi^2 = 41.8$, p<0.001), females ($\chi^2 = 178.9$, p<0.001), juveniles ($\chi^2 = 122.8$, p<0.001), and metamorphs ($\chi^2 = 16$, p<0.001) (Figure 6e).

Discussion

The results indicate there were differences in microhabitat use between the different sex and age *L. aurea* classes
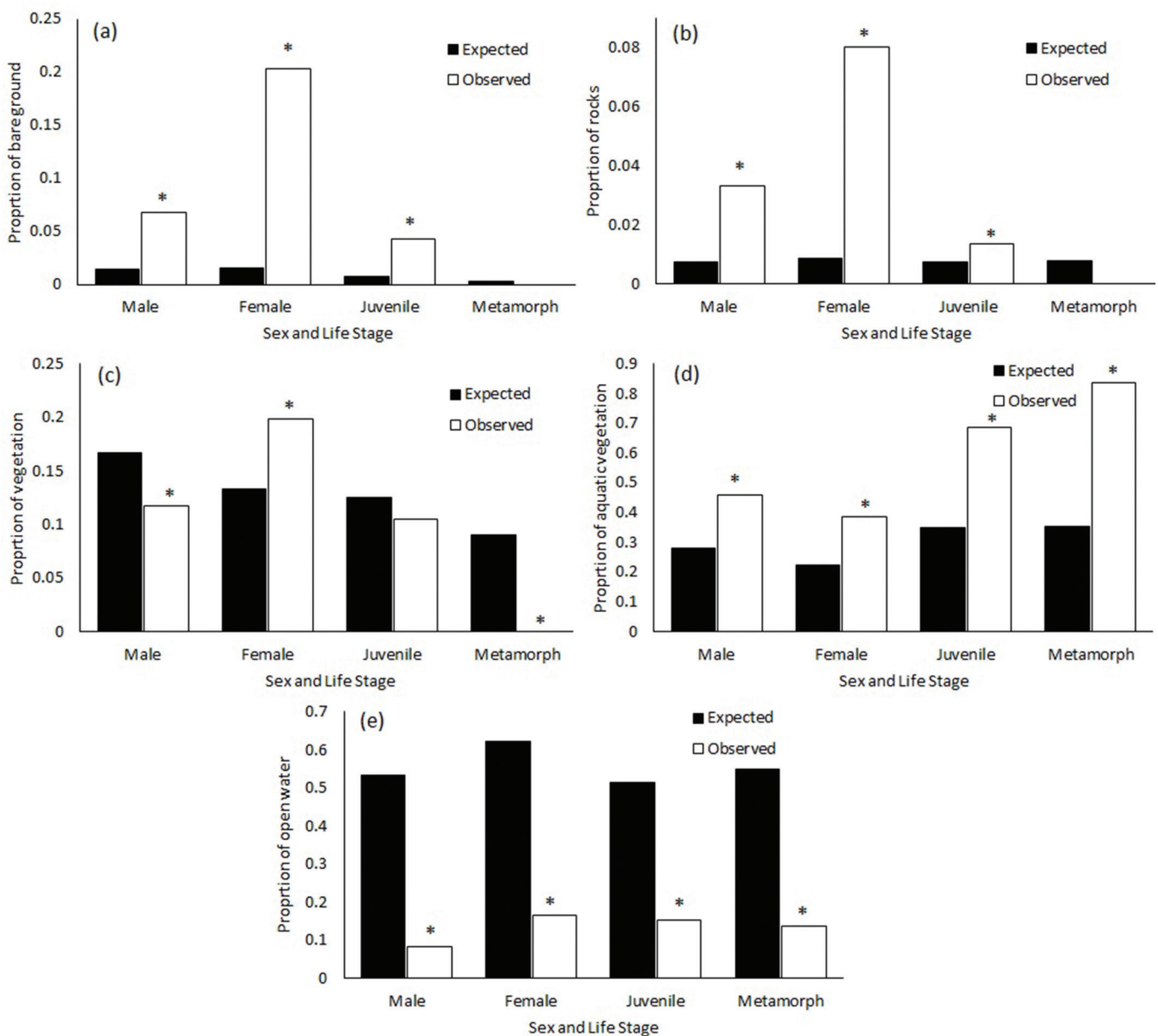
Figure 6. Proportion of observations of green and golden bell frogs (*Litoria aurea*) expected and observed, after accounting for detectability, for each sex and age class on Kooragang Island for (a) bare ground, (b) rocks, (c) vegetation, (d) aquatic vegetation, and (e) open water microhabitats. Asterisks represent significance (p<0.05) of Chi-square test.

during the active breeding season, and which may have management implications for attracting and supporting different individuals to particular areas. For example, female *L. aurea* appear to be the limiting resource in populations (Pickett *et al.* 2015), mainly due to the relatively long time to reach sexual maturity (Mahony *et al.* 2013), coupled with the low survival rate due to the impact of the amphibian disease chytridiomycosis (Stockwell *et al.* 2010; Stockwell *et al.* 2008). As they were the only class to actively select for terrestrial vegetation, female occupancy may be encouraged by increasing the amount of terrestrial vegetation surrounding waterbodies. Terrestrial vegetation is also crucial for juveniles as it provides protection from predation and conspecifics as they actively disperse to colonize new sites (Goldingay and Lewis 1999; van de Mortel and Goldingay 1998). Moreover, since sub-adults (metamorphs and juveniles) have a low survival rate, we recommend they be released onto sites with a large area of aquatic vegetation to provide opportunities for foraging while also offering protection from predation. Large rock piles have also been widely used in past *L. aurea* management due to their recommendation in habitat guidelines produced by government conservation agencies (Pyke and White 1996). However, they were only selected for by adults and juveniles in this study, but at a very low frequency. Therefore, it may not be an important microhabitat for parts of conservation programs that only deal with tadpoles, metamorphs, and juveniles; such as captive-breeding programs prior to release.

The most important microhabitat selected by every *L. aurea* class was aquatic vegetation. These results concurs with previous studies (Garnham *et al.* 2015; Hamer *et al.* 2002) and should be the focus in all future management programs, as previously suggested (Goldingay and Lewis 1999; Pyke and White 1996). Aquatic vegetation such as submerged, emergent, and fringing plants provide critical breeding microhabitats for this species by providing oviposition sites for adults and shelter for tadpoles (Hamer and McDonnell 2008; van de Mortel and Goldingay 1998). It also serves as an important microhabitat for adults and juveniles which utilize it to forage, bask, and as shelter (Pyke and White 2001). Moreover, aquatic vegetation offers protection from predators, which is important for all age and sex classes (Goldingay and Lewis 1999; Goldingay 2008). This microhabitat is especially important for metamorphs, which require to be near water and may be particularly vulnerable to desiccation; as well as for chorusing males, whose calls may attract predators (Pyke and White 2001).

Conversely, open water was used less than expected by all class groups. Although all life stages require aquatic resources, being in open water makes them vulnerable to predators; especially if other microhabitats that provide shelter are not available (Pyke and White 2001). Actively swimming or floating in open water would likely also use more energy, whereas on aquatic vegetation they can remain at rest in the water while still able to obtain foraging opportunities. However, breeding events such as amplexus were not observed in this study, which may have biased the outcomes. Previous research has reported that adult *L. aurea* males float on the surface of open water to actively chorus (Courtice and Grigg 1975; Thomson *et al.* 1996). Similar to other amphibian species with explosive breeding patterns (Daly 2014; Wells 1977), males have also been observed actively moving towards disturbances on the surface of open water (Ford 1986), presumably to seek opportunities with females or deter males from occupying their territorial space (Mahony, pers. comm.). Furthermore, ponds with open water would be expected to have higher water temperature, which could also influence spawning on many amphibian species (Hamer and Parris 2011). Therefore, future *L. aurea* research should focus on understanding how microhabitats are used during chorusing and reproduction.

Individuals from all classes, except metamorphs, were found on bare ground more than expected. Juveniles and adults may use bare ground to facilitate their sit and wait foraging behaviour (Heard *et al.* 2008), and although bare ground does not provide much protection against predators, it would allow a quick retreat into the water to evade them, assuming bare ground was within jumping proximity to the water (Heard *et al.* 2008). Bare ground is also important as it is commonly used for basking (Pyke and White 2001) which allows them to increase their body temperature allowing for better digestion and maximal growth (Hamer *et al.* 2003). Furthermore, *L. aurea* is known to occasionally overwinter in wet ground close to the water's edge (Garnham *et al.* 2015). Metamorphs were found less often on bare ground than predicted possibly due to their greater reliance on available water. In addition, metamorphs have restricted mobility making them an easier target for predators in open ground.

Terrestrial vegetation was used more than expected by females and less than expected by males and metamorphs. A previous study on female western toads, *Bufo boreas* also found females used vegetated areas more than males (Bartelt *et al.* 2004). This discrepancy is hypothesized to be due to the larger size of females. A larger body has a larger capacity to hold water and thus a reduced risk of dehydration, which would allow them to disperse to new sites through drier areas (Bartelt *et al.* 2004). These sex differences also occur in *L. aurea* with females larger than males (Pyke and White 2001). Males in this species also showing greater site fidelity, especially during the breeding season when males aggregate to chorus (Pyke and White 2001) and females travel to these ponds due to conspecific attraction (James *et al.* 2015; Pizzatto *et al.* 2015). Although metamorphs can be found in fringing grass and sedges (van de Mortel and Goldingay 1998), they may have been found in terrestrial microhabitats less than expected because of their site fidelity and their apparent inability to disperse. However, terrestrial

habitat is important when they become juvenile frogs and require cover when they actively disperse toward new ponds (Bower *et al.* 2013; Pyke and White 2001).

Rocks were used more than expected by adults and juveniles but not metamorphs. Rock piles, and other large solid substrates with crevices, may be selected for by *L. aurea* to bask and to provide protection from predators and unsuitable weather due to the stable microclimate and lower temperature variability in the small spaces between them (Garnham *et al.* 2015; Hamer *et al.* 2003). Similar results have been documented in another tree frog (*Bokermannohyla saxicola*), and have been hypothesized to help reduce predation by visually oriented predators (Sazima and Eterovick 2000). Since metamorphs require a greater reliance on water and are more likely to be preyed upon, the benefits of being in the open may not outweigh the risks.

Since many conservation projects on amphibians involve captive-breeding and their subsequent translocation to natural or semi-natural landscapes, the findings of the current study may improve survival of reintroduced individuals in future studies. The most appropriate plan should contain a mosaic of microhabitat types such as aquatic and terrestrial vegetation with patches of bare ground and a small proportion of large rocks. Previous research on this species on Kooragang Island indicate that a diversity of vegetation around the banks of waterbodies, such as *Juncus kraussii, Schoenoplectus litoralis,* and *Sporobolus virginicus* may encourage *L. aurea* presence (Hamer *et al.* 2002). Furthermore, while large rock piles have been utilized greatly in almost all past *L. aurea* habitat creation projects to provide for shelter and overwintering sites, placing large rocks as a management tool is expensive and time consuming. Reintroduction and habitat creation plans may which focus on researching cheaper alternatives, such as vegetation mounds which has recently been hypothesized to provide shelter (White and Pyke 2015). However, caution should be taken since the hardness of rocks and similar substances may be better at providing protection from climate and predators. Lastly, even if habitat is created to the best specification, a landscape approach is required due to their colonizing ability (Valdez *et al.* 2015) and their ability to disperse over long distances after translocation releases (Stamps and Swaisgood 2007). Therefore, any successful *L. aurea* habitat creation and reintroduction management plans should include nearby permanent waterbodies in their initiatives.

Habitat creation/restoration, reintroductions, and translocation projects are emerging as pivotal methods of species conservation management. Recognizing the differences in habitat use patterns between individuals within populations may give conservation managers useful information for to make informed decisions. By taking these differences into account and incorporating them into future management strategies, it may increase the chances of success in habitat creation or enhancement programmes.

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